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Publication date:
2013

Document Version
Publisher's PDF, also known as Version of record

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Presented at the 166th Meeting of Acoustical Society of America Fall 2013 Meeting, San Francisco, California, USA, December 2-6, 2013

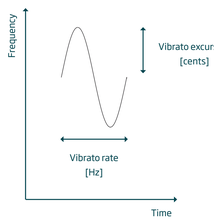
This study was concerned with the way in which the maximum acceptable vibrato excursion varies as a function of vibrato rate in normal-hearing (NH) musicians and non-musicians.

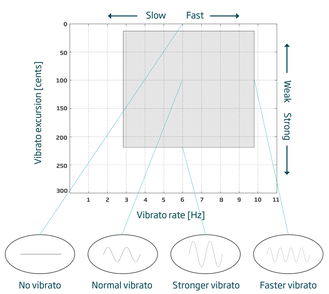
Background and aim of the study

Sound produced by the human voice is rich in frequency variations which convey important cues for speech intelligibility, sound segregation and the salience of sound sources [1-6].

This study focused on the frequency variations that occur in the vocal vibrato of human singing voices. Vocal vibrato is physically described as coherent fluctuations imposed on the harmonic components of sounds produced by the human voice. It is mainly characterized by two parameters: vibrato excursion and vibrato rate.

These parameters have been found to exhibit an interaction both in physical recordings of singers' voices [7-9] and in listener's preference ratings [10].





Research questions

1) Does the maximum acceptable excursion vary across vibrato rate?

2) If so, how does this interaction between vibrato rate and excursion compare with the maximum vibrato excursions produced by singers?

3) Does musical training affect the preference of the listeners?

Methods

Stimulus configuration

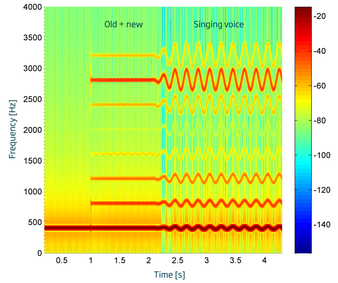
- Harmonic complex tone with first 8 harmonics of vowel /oh/.
- Coherent fluctuations applied by adding the same frequency shift M (cents) to all N components:

$$y(t) = \sum_{k=1}^{N} A_k \cos\left(2\pi f_k t + 2\pi \int_0^t f_k \frac{c_m(\tau)}{1200}\, d\tau\right),$$

$$c_m(\tau) = M \sin(2\pi f_m \tau)$$

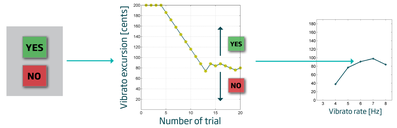
(k: harmonic number, Ak: harmonic amplitude, fk: harmonic frequency, M: the frequency shift in cents, fm: vibrato rate)

- Shimmer and jitter added for better simulation of natural vocal vibrato.
- Three temporal segments: "old+new heuristic" [4] and vibrato. Adding coherent fluctuations leads to the fusion of all components into a singing voice.



Spectrogram of the basic stimulus, showing its three temporal segments: 1) fundamental at 400 Hz, 2) all eight harmonics of the vowel /oh/, and 3) fluctuations (vibrato) imposed on the vowel. In the last segment, the doubling of the excursion for every harmonic can be seen (linear frequency axis).The colors indicate the normalized magnitudes of the frequency components in dB.

Procedure



- One-interval, two-alternative, forced-choice "Yes/No" task.
- The 50% point of the psychometric function was derived by means of a 1-up 1-down algorithm.
- Six reference values of vibrato rate: 3, 4, 5, 6, 7, and 8 Hz.
- The starting value for the excursion was 200 cents.
- For each presentation of the stimulus, the listeners were requested to give a "Yes/No" reply to the question "Can this sound be linked to a singing voice?".
- 6 reversals, step sizes of 14 and 4 cents.
- 3 repetitions.

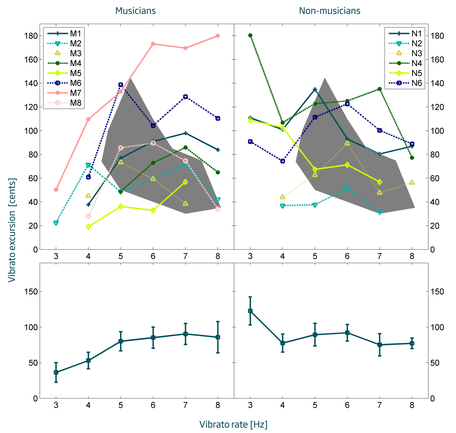
Listeners

- 14 NH listeners (8 musicians [M], 6 non-musicians [N]). M7 and M8 were elderly.
- All musicians had at least 5 years of musical training and practiced an instrument or singing on a regular basis.
- Non-musicians had never received any form of musical training and had not sung or practiced any instrument.

Presentation level

- Stimuli presented diotically at a moderate sound level.
- Component levels as in [11] with the fundamental component (400 Hz) set at 70 dB SPL.

Results



- The thresholds were found to range from 20 to 180 cents for the musicians, while this range was from 31 to 180 cents for the non-musicians.
- In all subjects, the adaptive procedure converged to a threshold for vibrato rates of 4-7 Hz. However, only 2 musicians and 4 non-musicians obtained thresholds for the 3-Hz rate, and 6 musicians and 4 non-musicians for the 8-Hz rate, the other listeners never judging the vibrato as appropriate for these rates.
- A two-way ANOVA showed no significant effect of musical education or vibrato rate on the thresholds.
- From the individual thresholds it can be seen that eleven out of fourteen listeners exhibited a peak in preferred excursion at the medium vibrato rates (5-7 Hz).

	M1	M2	M3	M4	M5	M6	M7	M8	N1	N2	N3	N4	N5	N6
1st peak	7	7	5	7	Increasing vibrato rate	5	Increasing vibrato rate	6	5	6	6	7	Decreasing vibrato rate	6
2nd peak		4				7						3		3

Discussion

Comparison with physical recordings

- The grey area indicates the measurements from a number of soprano voices presented in [7]. A range of almost 100 cents can be observed at 5.5 Hz between the minimum and maximum excursion produced by singers.
- Thresholds exhibit a peak as a function of rate, but at a rate which did not always correspond to the 5.5 Hz peak of the recordings.
- There may be a listener-dependent rate range (5-7 Hz) within which larger vibrato excursions are favoured.

Potential explanations for the non-significant effect of vibrato rate

- Thresholds at rates or 3 and 8 Hz were derived for only part of the listeners, consistent with the fact that very low and very high values ofvibrato excursion are shown in the literature not to be preferred by listeners [10].
- Additionally, the individual excursion maxima were located at different rates for the different listeners (5-7 Hz).

Conclusion

- No significant effect of musical experience or rate was found. However, the individual thresholds were found to vary across rate, indicating that most listeners' perception is not solely defined by the amount of vibrato excursion.
- Large across-subject variability was observed, which may be explained by the large spread of vibrato excursion found in physical recordings and thus the differences in musical preference of the listeners.
- Most of the listeners' thresholds exhibited a peak at medium vibrato rates. These rates did not consistently correspond to the 5.5-Hz peak measured in recordings, but suggested that there is a listener-dependent rate for which larger excursions are favored.
- Further work will investigate modifications on real recordings and also it will aim in more objective measures for quantifying the sensitivity to frequency changes. This would be relevant when studying auditory deficits experienced by elderly as well as hearing-impaired listeners.

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